Study of Joint Densities in Bituminous Airport Pavements

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In this paper, a research project (a) to collect data on field projects to determine joint density values currently obtained in the field, (b) to determine whether correlation exists between mat density and joint density results, and (c) to determine the differences between the use of in-place density and the use of percent compaction for density acceptance decisions is summarized. Data were collected on two runway paving projects selected by the FAA Eastern Region using cores and three nuclear density gauges (CPN M-2, Seaman C-75BP, and Troxler 3411-B). These data were analyzed statistically to identify current production capabilities with respect to joint densities and possible correlations between mat and joint density results. The findings indicate that joint density values are statistically significantly lower and more variable than density values obtained in the paving mat. This was true for both the core and nuclear gauge results on both projects studied. If joint density is to be considered an acceptance characteristic, it will therefore be necessary to use different acceptance limits for joint density than are currently used for mat density. There was a positive correlation between average lot mat and joint density results for both projects studied; however, the magnitude of the correlation differed between the projects. Several disadvantages of the use of the percent compaction approach are identified and discussed.

During 1978, the Federal Aviation Administration (FAA) Eastern Region incorporated a statistically based acceptance plan into its bituminous surface course specification (P-401). This specification provided for the determination of a price adjustment factor based on the relative acceptability of the pavement materials. In conjunction with the implementation of this specification, the FAA sponsored a research project (a) evaluating the performance of the specification, (b) making recommendations for improving existing specifications, and (c) expanding the scope of the statistical specification to include additional acceptance characteristics (*1*). Subsequent research addressed the use of the Marshall properties in a price adjustment acceptance approach (*2*).

The introduction of joint density as an acceptance test and the use of nuclear density gauges for pavement evaluation were not addressed by thorough research. Limited data suggested that joint densities are consistently lower than mat densities (*3*). In 1981, the FAA instituted a price adjustment provision for joint density on its runway paving project at the National Aviation Facilities Experiment Center (NAFEC) outside Atlantic City, New Jersey. The FAA discontinued the use of nuclear gauges for acceptance decisions after research at NAFEC showed a lack of accuracy, leading to a lack of confidence in the consistency and accuracy of nuclear gauges.

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The limited data from the NAFEC project were not sufficient grounds on which to base a rational acceptance plan for joint density that incorporates appropriate acceptance limits with the possible use of price adjustments. A thorough study of joint densities and nuclear gauge readings obtained under field conditions was essential if the FAA was to consider using joint density and nuclear gauges in its acceptance approach for bituminous pavements. To this end, two construction sites were selected on which to gather joint density and nuclear gauge data. The findings with respect to joint density of the research effort on these projects are presented in this paper.

The objectives of the joint density phase of the research were to determine whether joint density should be included in the FAA's acceptance procedure for bituminous runway pavements. The specific objectives were

1. To collect data on field projects to determine joint density values currently obtained in the field,
2. To determine whether correlation exists between mat density and joint density results, and
3. To determine the differences between the use of in-place density and the use of percent compaction for density acceptance decisions.

To meet the outlined objectives, the research was conducted in three major phases. First, field data were gathered on construction projects from cores and by using three nuclear density gauges (Troxler 3411-B, Seaman C-75BP, and CPN M-2). Next, these data were analyzed statistically to identify current production capabilities and possible correlations between mat and joint density results. Finally, the results of the first two phases were used to investigate potential tolerance limits and acceptance procedures.

Nuclear density readings were taken where mat and joint cores were drilled for acceptance testing. Additional nuclear density readings were also taken with each gauge at random locations to evaluate correlations between the mat and joint densities.

A statistical analysis was conducted on the data to determine parameters that can be used to represent the field construction process capability. Mean and standard deviation values for both joint and mat densities were developed for each project. In addition, a correlation analysis was conducted to investigate the potential relationships between mat density and joint density. All statistical analyses were conducted using the Statistical Analysis System (SAS) (*4*).

Because runways are relatively wide, up to 150 ft or more, there are many longitudinal construction joints required. Because limited data indicate joint densities to be less than mat densities, it is possible that these lesser densities may lead to more rapid pavement deterioration at the joints. The research was designed to establish joint densities currently obtained on projects, to determine whether these densities are less than those obtained on the mat, and to determine whether joint density should be considered separate from mat density in acceptance decisions.

DATA COLLECTION

The portion of the research dealing with data collection was divided into two main areas. The first was to determine the type of data to collect. The second was to limit variability by ensuring consistency in the data collection procedures. Data for the research were gathered on two construction projects during 1984. The projects were selected by the FAA Eastern Region. Data were to have originally been collected on three projects, but the FAA Eastern Region was only able to identify two suitable projects for which joint data could be obtained.

Type of Data

For research purposes on the projects studied, four cores were collected for determining joint density in addition to the four cores normally drilled for mat density determination. Nuclear gauge readings were also taken at locations where cores were drilled. Nuclear gauge readings were also taken at random locations on the joints and within the mat. The ease and speed of the nuclear gauges allowed a large number of locations (approximately 30) to be selected from each paving lot.

Data Collection Procedures

Two projects were selected by the FAA Eastern Region for the collection of field data. The projects studied were the Morristown, New Jersey, Municipal Airport and Rochester-Monroe County Airport in Rochester, New York. Data were collected by obtaining cores and also with three different nuclear density gauges (Troxler 3411-B, Seaman C-75BP, CPN M-2).

Data for each project consisted of the densities of the compacted pavement materials. The compacted materials were tested on a lot basis, with a lot consisting of 1 day's production, not to exceed 2,000 tons. Eight cores were selected for each lot, four for the mat and four for the joints. The core locations on the mat and the joint were identified by the resident engineer on the project. The random sampling and testing procedures used on the projects are outlined in the FAA *Eastern Region Laboratory Procedures Manual* (ERLPM) (*5*).

Readings were obtained with each of the three nuclear density gauges at the exact locations where cores were to be drilled. The nuclear readings were taken immediately before drilling to guarantee no change in pavement density between the time of the nuclear gauge readings and the drilling of the cores. Each individual gauge reading was the average of two readings, with the gauge rotated 180° prior to taking the second reading. While taking the joint density readings at Morristown, the gauges were oriented so that the radiation source and the detector were aligned longitudinally along the joints between the pavement sections. On the Rochester project, two joint readings were obtained for each sample location, one with the gauge parallel to the joint (as at Morristown) and one with the gauge perpendicular to the joint. The individual perpendicular gauge readings were the average of two readings with the gauge rotated 180° between readings. The radiation source and detector of the gauge were on opposite sides of the joint between the pavement sections for each of the two readings.

DATA ANALYSIS

After collection, the data were transferred to the computer in preparation for analysis. Separate analyses were conducted for each project. The Statistical Analysis System (SAS) (*4*) was used for both the data management and the analysis.

Scatter Plot Procedure

Scatter plots of the data were developed to investigate trends and correlations between the average mat and joint densities for each lot. The data were also plotted by lot number to determine whether any time trends were present. Because density values for acceptance decisions on the projects studied were based on percent compaction, that is, the percentage of the laboratory Marshall density value that was attained by the field cores, the core and gauge density results were also converted to percent compaction values and then plotted. To determine the relationship between mat and joint density, for each project the average mat density and the average joint density for each lot were plotted against the lot number.

Hypothesis Tests

To determine whether mat densities differed from joint densities on each project, t-tests and F-tests were used to compare the mat and joint density means and variances for each lot of material. The TTEST procedure in SAS computes a t-statistic for testing the hypothesis that the means of two groups of observations, for example, mat and joint densities, are equal and an F-statistic for testing the equality of the variances. The TTEST procedure was also conducted on the mat and joint percent compaction results for each project.

Correlation Analysis

In addition to the scatter plots, correlation coefficients were calculated to quantify the relationships among the data. The correlation coefficient measures the amount of association between two variables, and is based on a linear relationship.

RESULTS OF DENSITY DATA ANALYSIS

The results of the data analysis procedures outlined in the previous section are presented and discussed in this section. Density readings were obtained where cores were drilled for acceptance purposes and at other random locations within each lot. In the discussions that follow, core or nuclear density readings taken at coring locations are referred to as acceptance tests. Nuclear gauge readings taken at locations where cores were not drilled are referred to as random tests.

Project Specification Requirements

The specification requirements for joint density differed on the two projects studied. On the Morristown project, joint density was an acceptance item with a payment adjustment provision included in the contract. There was a definite incentive for the contractor to achieve dense joints because there was the potential for payment reductions if the specification requirements were not met. The specifications at Morristown stipulated that four cores be drilled at random locations along the joints for each lot. An estimated percentage within limits (PWL) value of 90 or greater was required for 100 percent payment. The lower acceptance limit was 94.3 percent of the laboratory Marshall density.

There was no specification requirement for joint density on the Rochester project. Four cores were drilled and tested by the researchers at random locations along the joints for each lot; however, the incentive to achieve high joint densities associated with the price adjustment provisions on the Morristown project was not present at Rochester. This difference in payment provisions between the projects may have an effect on the joint densities obtained at the respective sites.

Scatter Plots

Plots of the mat density and joint density values obtained on the projects are shown in Figures 1-8. Figures 1-4 show the results from the Morristown project, whereas the Rochester results are shown in Figures 5-8. Each plot shows the mean mat and joint densities for each lot along with the corresponding maximum and minimum values obtained. Figures 1 and 5 show the core density acceptance test results. Figures 2 and 6, 3 and 7, and 4 and 8 show the combined values for both the acceptance and random tests for the CPN, Troxler, and Seaman gauges, respectively.

As shown in the figures, the mat density mean values are consistently higher than the joint mean densities on both projects for the cores and for all three nuclear gauges. It is also apparent that the joint density results are more variable than the mat density values. This variation is indicated by the larger spreads between the maximum and minimum values for the joint densities. These differences in means and variability are quantified in the statistics presented in the next section.

Hypothesis Testing

Data were collected from 10 lots on the Morristown project and 18 lots at Rochester. This procedure yielded a total of 80 core densities (40 mat and 40 joint) and 384 readings for each of the nuclear gauges (total of 1,152 nuclear density values) at Morristown. At Rochester, a total of 144 core densities (72 mat and 72 joint) and 1,242 nuclear gauge readings (414 for each of the gauges) were obtained.

To further investigate the trends with regard to the mean densities and the variability identified in the plots in Figures 1-8, the TTEST procedure (PROC TTEST) in SAS was used to perform hypothesis tests on the data. PROC TTEST conducts hypothesis tests to test the assumptions of equal variances and equal means between two sets of data. In this

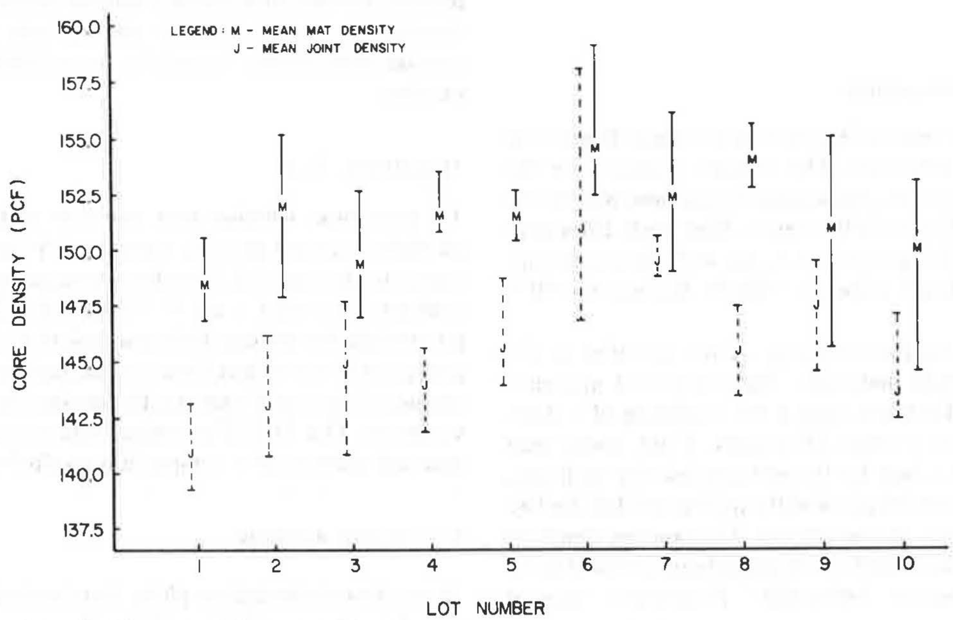

FIGURE 1 Plot of core density results for the Morristown project.

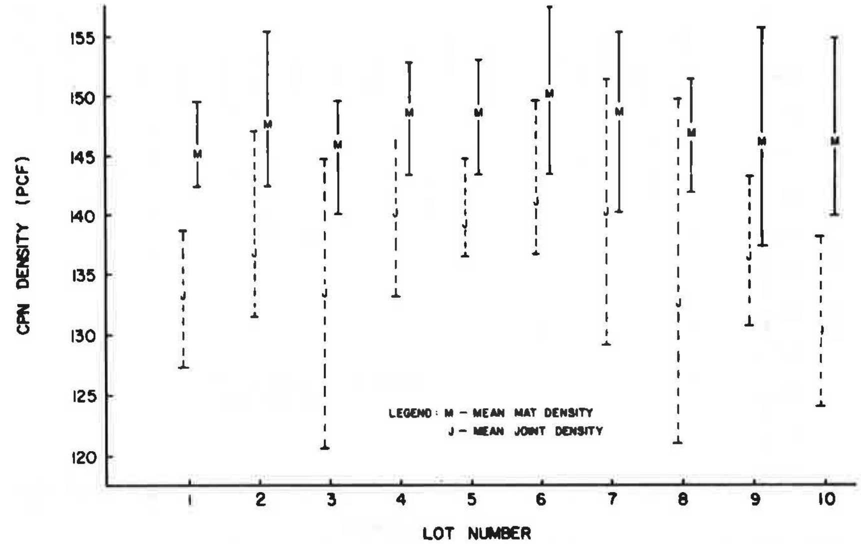

FIGURE 2 Plot of CPN gauge density results for the Morristown project.

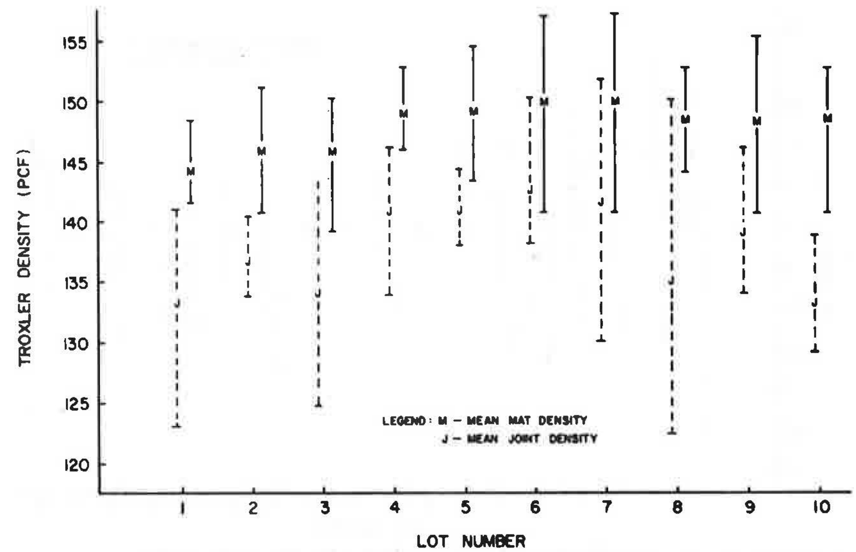

FIGURE 3 Plot of Troxler gauge density results for the Morristown project.

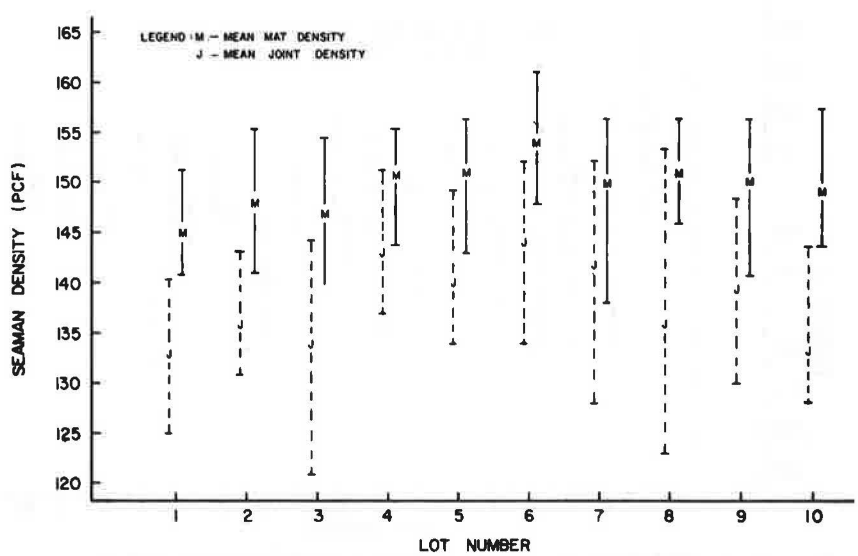

FIGURE 4 Plot of Seaman gauge density results for the Morristown project.

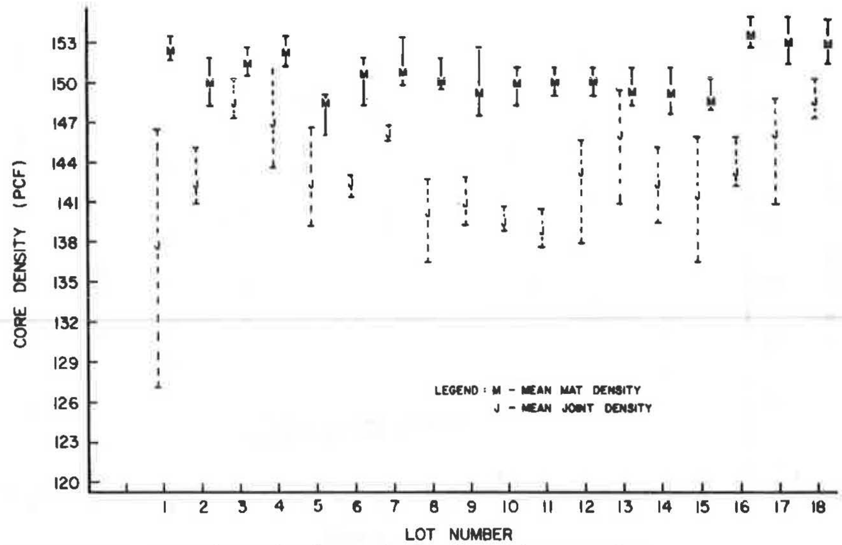

FIGURE 5 Plot of core density results for the Rochester project.

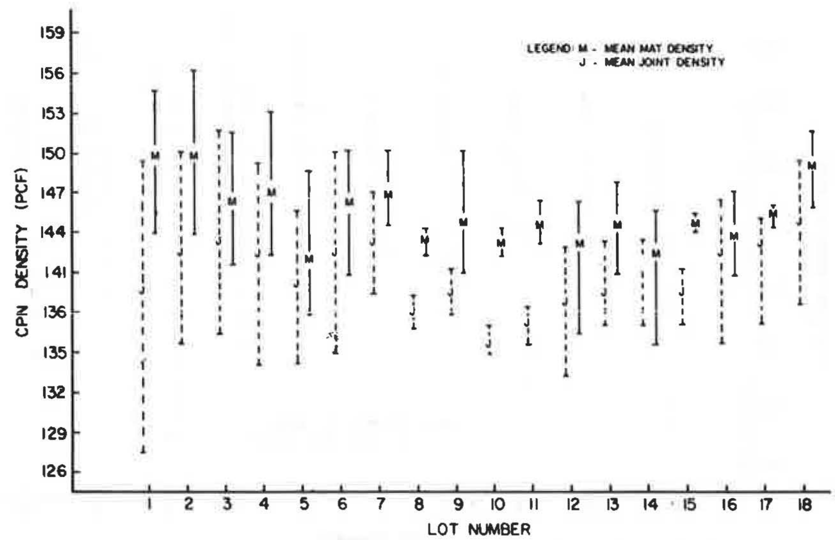

FIGURE 6 Plot of CPN gauge density results for the Rochester project.

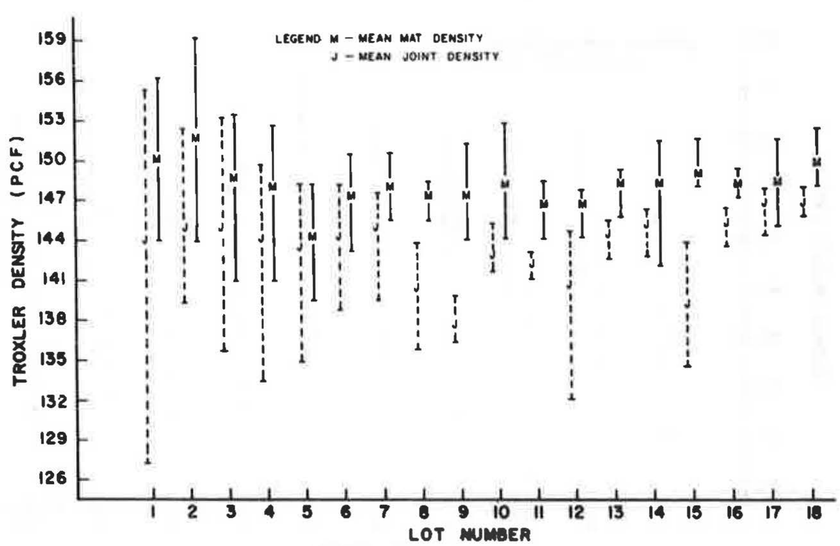

FIGURE 7 Plot of Troxler gauge density results for the Rochester project.

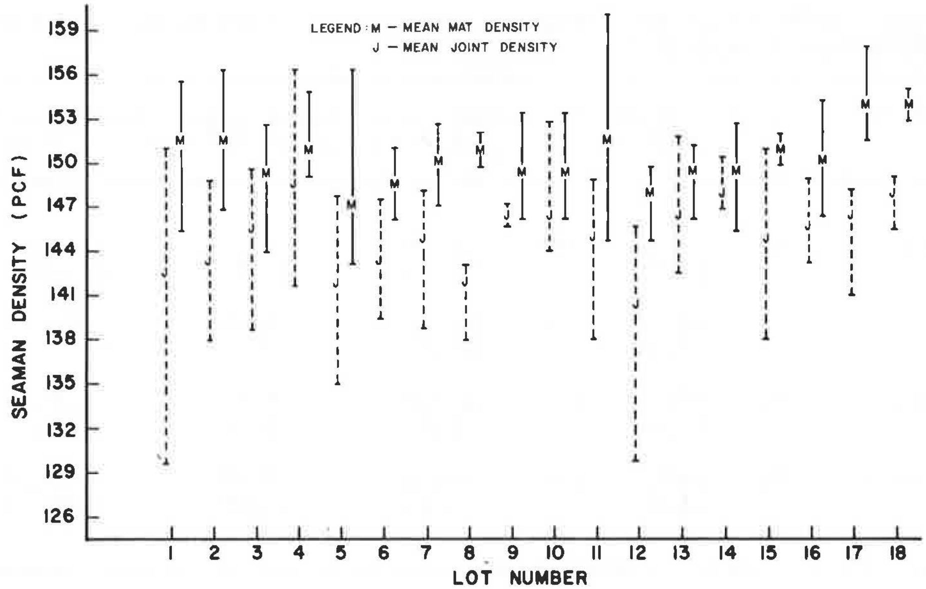

FIGURE 8 Plot of Seaman gauge density results for the Rochester project.

case, the two sets of data to be tested are the mat and joint density results from the two projects. Tables 1 and 2 present the hypothesis test results for the data from Morristown and Rochester, respectively.

In Table 1, the source column identifies whether the mean is from the core, CPN, Troxler, or Seaman density values. The last two columns list the results of the F-tests and t-tests conducted on the data. The F-statistic is used to test the hypothesis that the variances of the two data sets are equal. The term "Prob $> F$" is the probability of obtaining an F value as large as the one shown if the hypothesis that the variances are equal is true. In Table 1, therefore, there is 0.0001 or less chance that the variances of the mat and joint densities are equal for any of the three nuclear gauge results. Similar results are presented in Table 2 for the Rochester data. These are sufficient grounds to assume that the joint density values are more variable than the mat densities when nuclear gauges are used. For the core results, the Morristown mat and joint variances are not significantly different (0.269 level of significance), but the Rochester values are significantly different at the 0.0001 level.

The t-statistic is used to test the hypothesis that the means of two data sets are equal. The term "Prob $> |t|$" is the probability of obtaining a t value with absolute magnitude as large as the one shown in the table if the hypothesis that the means are equal is true. In Table 1, there is essentially no chance (0.0001 or less) that the means of the data sets are equal for any of the sources. Because similar results are displayed in Table 2 for Rochester, it is reasonable to assume that the joint densities obtained are statistically significantly different from the mat densities obtained on the projects.

Correlation Analysis

Because there is no direct correspondence between the individual mat and joint density values, it is not possible to correlate the individual values. It is possible, however, to correlate the average mat and joint density values for each lot. Unfortunately, this does not provide a great deal of information due to the small number of lots (10 and 18) on each project. Table 3 presents a summary of the correlation coefficients between the average lot mat and joint densities for each project.

There is a positive correlation between the average mat and joint densities on the Morristown project. Although the correlation coefficients for the Rochester data are positive, the magnitudes are not large enough for three of the sources to preclude the possibility of zero correlation at the 0.05 level of significance. The core, Troxler, and Seaman results are not significantly different from zero at the 0.087, 0.168, and 0.150 levels of significance, respectively.

RESULTS OF PERCENT COMPACTION ANALYSIS

The acceptance procedures employed by the FAA specify that the field density be determined as a percentage of the laboratory density obtained from the Marshall tests. This value is referred to as the percent compaction. If the same percent compaction approach is to be maintained, it is necessary to also consider the density values for the projects studied from the standpoint of their percent compaction values.

Both projects studied had price adjustment provisions for mat density based upon the estimated percentage within limits (PWL) value for the lot. An estimated PWL value of 90 or greater was required for 100 percent payment, and the lower acceptance limit was 96.7 percent of the laboratory Marshall density. The Morristown project also had a price adjustment provision for joint density that required a PWL of 90 or greater for 100 percent payment, and the lower acceptance limit was 94.3 percent of the laboratory Marshall density.

Using percent compaction introduces another component of variability that is not present in the density plots. The

TABLE 1 RESULTS OF HYPOTHESIS TESTS ON MAT AND JOINT DENSITY DATA FOR THE MORRISTOWN PROJECT

Source	No.	Mat Mean (Std Dev)	No.	Joint Mean (Std Dev)	F-statistic (Prob > F)*	t-statistic (Prob > |t|)#
Core	40	151.5 (3.3)	40	145.6 (3.9)	1.43 (.269)	-7.39 (.0001)
CPN	192	147.1 (4.0)	192	136.5 (5.9)	2.18 (.0001)	-20.77 (.0001)
Troxler	191	148.8 (3.9)	191	138.7 (5.7)	2.08 (.0001)	-19.48 (.0001)
Seaman	192	149.5 (4.6)	192	138.2 (6.6)	2.09 (.0001)	-20.19 (.0001)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 2 RESULTS OF HYPOTHESIS TESTS ON MAT AND JOINT DENSITY DATA FOR THE ROCHESTER PROJECT

Source	No.	Mat Mean (Std Dev)	No.	Joint Mean (Std Dev)	F-statistic (Prob > F)*	t-statistic (Prob > |t|)#
Core	72	150.7 (2.1)	72	143.3 (4.3)	4.13 (.0001)	-13.07 (.0001)
CPN	207	141.8 (3.7)	207	141.8 (4.4)	1.40 (.016)	-11.35 (.0001)
Troxler	207	147.7 (3.2)	207	143.7 (4.1)	1.64 (.0004)	-11.05 (.0001)
Seaman	207	150.0 (2.9)	207	144.6 (4.1)	1.99 (.0001)	-15.26 (.0001)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

percent compaction value is the result of dividing the field density by the Marshall laboratory density. Because both the field and laboratory density tests have some inherent variability, the percent compaction results are likely to be more variable than the case when only the field density is considered. The differences between the mat and joint results for percent compaction are quantified and discussed in the next section.

Hypothesis Testing

Percent compaction values were determined for the acceptance test results for each of the projects studied. For the Morristown project, 40 mat and 40 joint percent compaction values were determined for the core densities and for the readings for each of the gauges. For the Rochester project, a total of 144 (72

TABLE 3 CORRELATION COEFFICIENTS BETWEEN AVERAGE LOT MAT AND JOINT DENSITIES

Project	Source	Coefficient (R)	Prob > |R|*
Morristown	Core	.666	.036
(10 lots)	CPN	.829	.003
	Troxler	.808	.005
	Seaman	.776	.008
Rochester	Core	.414	.087
(18 lots)	CPN	.496	.036
	Troxler	.339	.168
	Seaman	.354	.150

*Prob > |R| - probability of obtaining an R value as large as the one shown if the true correlation is zero.

mat and 72 joint) percent compaction values were determined for each of the sources (i.e., cores and the three gauges).

The TTEST procedure in SAS was used to perform hypothesis tests on the data. The data sets tested by the procedure were the mat and joint percent compaction results. The analysis was conducted individually for each of the projects. Tables 4 and 5 present the hypothesis test results for the data from Morristown and Rochester, respectively. These tables are analogous to Tables 1 and 2, which present results from a similar analysis on the field density values.

For all four sources for each project, the mat values are statistically significantly larger than the joint values at the 0.0001 significance level. This is to be expected because the mat and joint percent compaction are both calculated from the same laboratory density, and the mat field density values are shown to be higher than the field joint density values in Tables 1 and 2.

The joint standard deviations are larger than the mat standard deviations for each of the sources for both of the projects. However, the differences are not statistically significant (0.05 level) for the core, CPN, and Troxler values at Morristown or for the CPN and Seaman values at Rochester.

RESEARCH FINDINGS

The major findings of the research effort with respect to joint density included the following:

1. Joint density and percent compaction values were consistently and statistically significantly lower than mat density and percent compaction values for both projects studied. This relation was true for both the nuclear gauge and core results, confirming the previous limited data that were available.
2. Joint density values were statistically significantly more variable than the mat density values for the nuclear gauges on both projects. The joint core results were significantly more variable than the mat core results for the Rochester data but not for the Morristown data. The percent compaction joint results were not as consistently more variable than the mat results; however, the same general trend was still apparent.
3. There was a positive correlation between average lot mat and joint density results for each project studied. However, the magnitude of the correlation was not consistent for the two projects.
4. The mat percent compaction results were significantly larger than the joint percent compaction results for all three gauges and for cores on both projects.
5. The core percent compaction results were generally statistically significantly larger than the nuclear gauge percent compaction results.

ACCEPTANCE PLAN RECOMMENDATIONS

This research has shown that the joint density values attained on projects are significantly smaller than the mat density values. If joint density is to be considered an acceptance characteristic and evaluated in the same manner that mat density is evaluated, then appropriate acceptance limits must be established. The current mat density acceptance procedures based on the PWL can also be used for joint density if appropriate acceptance limits are established.

TABLE 4 RESULTS OF HYPOTHESIS TESTS ON MAT AND JOINT PERCENT COMPACTION DATA FOR THE MORRISTOWN PROJECT

Source	No.	Mat Mean (Std Dev)	No.	Joint Mean (Std Dev)	F-statistic (Prob > F)*	t-statistic (Prob > |t|)#
Core	40	97.0 (2.0)	40	93.2 (2.1)	1.07 (.841)	-8.51 (.0001)
CPN	40	94.5 (2.9)	40	87.3 (3.6)	1.54 (.182)	-9.99 (.0001)
Troxler	40	95.2 (2.5)	40	88.7 (3.1)	1.55 (.177)	-10.34 (.0001)
Seaman	40	96.2 (2.4)	40	88.8 (4.1)	2.90 (.001)	-9.71 (.0001)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

TABLE 5 RESULTS OF HYPOTHESIS TESTS ON MAT AND JOINT PERCENT COMPACTION DATA FOR THE ROCHESTER PROJECT

Source	No.	Mat Mean (Std Dev)	No.	Joint Mean (Std Dev)	F-statistic (Prob > F)*	t-statistic (Prob > |t|)#
Core	72	98.2 (1.4)	72	93.5 (2.8)	3.89 (.0001)	-12.89 (.0001)
CPN	72	94.9 (2.3)	72	91.7 (2.9)	1.58 (.057)	-7.37 (.0001)
Troxler	72	96.0 (2.1)	72	93.2 (2.9)	1.96 (.0004)	-6.56 (.0001)
Seaman	72	97.7 (2.6)	72	94.3 (3.0)	1.38 (.181)	-7019 (.0001)

* - probability of obtaining an F value as large as the one shown if the variances are actually equal

\# - probability of obtaining a t value as large as the one shown if the means are actually equal

The current FAA procedures allow for full payment for a lot of material if the estimated PWL value for the lot is 90 or greater. If this same philosophy is applied to the joint density acceptance decision, then the lower acceptance limit for joint density can be calculated. Because the projects on which data were collected were selected by the FAA Eastern Region to be indicative of the quality level that can be attained on typical projects, the mean values for the projects can be used to establish the acceptance limits. The joint percent compaction results for Morristown and Rochester are presented in Tables 4 and 5. For Morristown, the mean and standard deviation for the joint core percent compaction values were 93.2 and 2.1, respectively. For Rochester, the corresponding values were 93.5 and 2.8.

The Morristown project had a price adjustment provision for joint density, whereas the Rochester project had no joint density specification requirement. The price adjustment provision at Morristown may be responsible for the smaller standard deviation at Morristown compared with that at Rochester. The mean values for the two projects are very similar. If the representative values for high-quality construction are based on the results of these projects, then it may be assumed that it is reasonable to expect that the higher quality of the values can be obtained in the field. The acceptance limits could then be based on a population mean and standard deviation of 93.5 and 2.1, respectively.

With the mean and standard deviation for the joint population established, a table of the normal distribution can be used to determine the acceptance limit as the value that has 90 percent of the population greater than it. This value will be 1.282 standard deviations below the population mean (*6*). For the population in question, the acceptance limit would therefore be 93.5 - (1.282 · 2.1) = 90.8.

This approach for establishing the acceptance limit is based on the assumption that the two projects studied are indicative of acceptable construction quality levels. Because the projects were selected by the FAA to be indicative of such quality, the results should yield an appropriate acceptance limit. If it is believed that these projects are not indicative of acceptable quality construction, then the same procedure could be used to establish the acceptance limit based on the population mean and standard deviation that were considered by the FAA to be indicative of an acceptable quality level.

Comments on the Percent Compaction Approach

The FAA has traditionally used the percent compaction based on the laboratory Marshall density for determining the field compaction values. There are several potential disadvantages to this approach that should be noted. The percent compaction approach introduces another element of variability into the acceptance process, that is, the determination of the laboratory density value. The percent compaction value is the result of dividing the field density by the Marshall laboratory density. Because both the field and laboratory density tests have some inherent variability, the percent compaction results have an added element of variability from the laboratory density that is not present when only the field density is considered.

Another potential problem is the fact that there is no direct correlation between the individual laboratory densities and the field density results. This lack necessitates the use of an average laboratory density against which each of the individual field densities is measured. This averaging process introduces another potential source of variability into the percent compaction results.

A final problem that can be encountered with the use of the percent compaction approach relates to the situation when a cold joint is formed by placing material from the current lot against material from a previously placed lot. The problem is selecting which of the laboratory densities, that is, from the new lot being placed or from the old lot already in place, should be used to determine the percent compaction.

For example, if the old lot had an average laboratory density of 150 lb/ft^3 and the new lot has a laboratory density of 155 lb/ft^3, what is the percent compaction if the joint core density is 145 lb/ft^3 ? If the new laboratory density is used, then the percent compaction is 145/155 · 100 = 93.5. However, if the laboratory density of the old lot is used, then the percent compaction is 145/150 · 100 = 96.7.

The procedure that was used by the FAA on the projects studied was to use the laboratory density from the new lot as the base against which to measure percent compaction. This procedure was therefore the one that was used in developing percent compaction values presented in this paper. It appears reasonable to use the smaller of the two laboratory densities to calculate percent compaction in a situation such as the one just presented. Another possibility is to use the average of the two laboratory densities in calculating percent compaction.

An approach that avoids these problems with the percent compaction procedures is to base acceptance on the in-place air voids determined from the specific gravities of the cores and the maximum specific gravity for the cores as measured by ASTM D-2041. This approach eliminates the added variability component introduced by the laboratory density and avoids altogether the problem of which laboratory density to use when two lots form a construction joint. The in-place air voids approach has the disadvantage of not having the large amounts of historical data that the FAA already has available for the percent compaction approach. The in-place air voids approach is recommended as a viable alternative that eliminates the problems associated with applying the percent compaction approach to joint density acceptance decisions.

ACKNOWLEDGMENT

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